Mobile To Hub Implementation and Simulation

There are a number of interesting issues in the Hub modem implementation. The Mobile has a continuous unmodulated Pilot available which provides phase, frequency, and time references. Since the same Pilot serves all mobile users, the cost is very little. The Hub, however, has no Pilot to derive phase, frequency and time. These items must be tracked using the Mobile's data transmissions.

To increase the overall capacity of the system, it is desirable to "not transmit" during quiet times (i.e. when a user is not talking). This presents a problem for the Hub since it uses the transmissions to get phase, frequency and timing information. To address this problem, the framing and preamble structure was implemented. This is discussed in greater detail below.

Users in heavily faded and shadowed environments further complicate the Hub modem. These users have the unfortunate side affect of having the signal fade while the noise/interference remains high (both signal and interference fade together in the Mobile modem). While in the harsh environment, coherent demodulation becomes very difficult. As a solution, the Hub will have two operational modes. In the unobstructed environments (highways, K=40 areas) the Hub will use BPSK demodulation. BPSK gives very good bit error performance in these areas. In the harsher environments (K<4) DPSK demodulation will be used.

Hub Simulation

The block diagrams for Hub processes modeled by the simulation are given in figure 6-3 for the BPSK mode and figure 6-4 for DPSK. The diagrams show the high level interconnections of the various loops. The primary difference between the diagrams is the phase tracking loop. The BPSK mode uses a phase loop to maintain a phase reference and the DPSK mode doesn't. The actual flow within the simulation program is shown in figures 6-5 and 6-6. The simulation flow is mathematically equivalent to the preceding diagrams. The major difference is the combination of other user noise and thermal noise into a single noise process.

Hub Framing and Preamble

To provide a Hub mechanism for phase synchronization, frequency tracking, detection of data present/absent, and interleaving, the framing and preamble structure was implemented. Each frame is 50 msec long and consists of two 25 msec interleaved blocks. Each interleaved block contains 20 symbols of preamble. The framing/preamble structure is illustrated in figure 6-1 below.

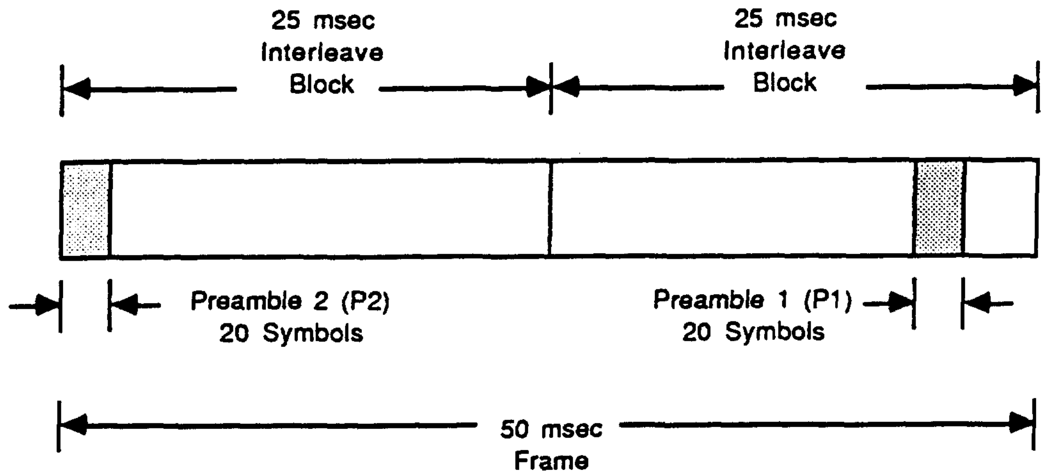

Figure 6-1—Framing structure.

The P1 preamble consists of 20 symbols and is always transmitted near the end of the second interleaved block (exactly 40 symbols from the end). The P2 preamble consists of 20 symbols and is always transmitted as the first 20 symbols of the first interleaved block. Forty symbol times separate the P1 and P2 preambles. The somewhat confusing convention of calling the first preamble P2 and the second preamble P1 makes more sense when multiple frames are viewed back to back. When viewed back to back, the P1 preamble can be seen to be 40 symbols from the P2 preamble in the following frame.

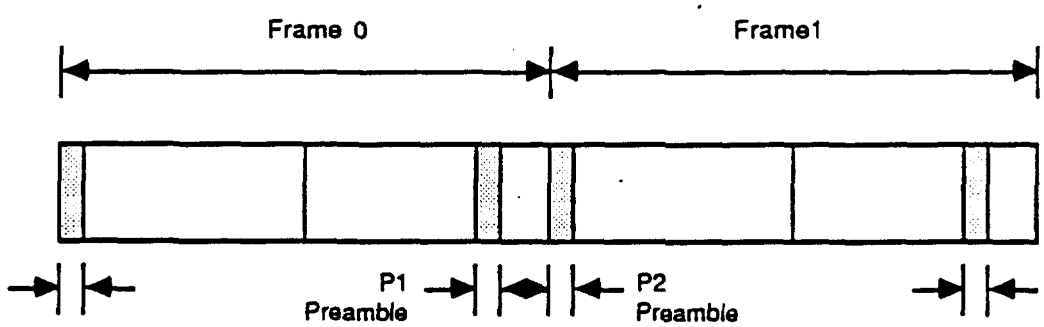

Figure 6-2—P1 and P2 preamble usage.

The preambles are transmitted *inband*.. Space for the preamble symbols is made available by *code puncturing*. Code puncturing is accomplished by sending preamble symbols instead of the code symbols. It is up to the Viterbi decoder to reconstructed the missing symbols from the stream of received symbols. In the Hub (and Mobile), 1 out of every 36 symbols is replaced by a preamble symbol at 9600 bps and 1 out of every 60 symbols is replaced by a preamble symbol at 16000 bps.

The hub makes use of the P1 and P2 preambles in several ways. The P1 and P2 preamble separation of forty symbols is enough to allow the Hub to make frequency error estimates and drive a first order frequency loop. However, the preambles are close enough to allow combination and use as an initial phase estimate for the phase loop when operating in the BPSK mode. The third function of the P1 and P2 preambles is the detection of data present or absent. The preambles are DPSK modulated. If P1 and P2 have the same phase, data is present. If they have opposite phase, data is absent.

The first *data absent* frame following a burst of *data present* frames actually contains 24 symbols of noninterleaved data called the *tail*. The tail is used to flush out and return the Viterbi Decoder to the zero state. All data bursts are assumed to start in the zero state and tail off at the end.

Hub Frequency Loop

The Hub uses a first order frequency loop to drive a hardware digital frequency synthesizer. Block diagrams of the frequency loops for the BPSK and DPSK modes can be found in figure 6-7 and figure 6-8. In the BPSK mode, the frequency loop is suspended while data is present. While suspended, frequency is tracked by the phase tracking loop. At the end of a data burst (a data burst is defined to be consecutive frames in which data is present), the frequency synthesizer is updated from the phase loop's frequency register and the frequency loop is resumed. In the DPSK mode, the frequency loop runs all the time. A correction is applied on each new frame. The frequency error detector is the cross product of the P1 and P2 preambles in both the BPSK and DPSK modes.

Hub Phase Loop

The Hub supports both BPSK and DPSK. However, the phase tracking loop operates only in the BPSK mode. This loop is a digital second order loop with a damping factor of $1/\sqrt{2}$. The loop bandwidth is 100 Hz. The Hub uses a significantly narrower bandwidth than the Mobile.

For BPSK, the phase detector is the in-quadrature Q component of the signal modified by the sign of I (Q*SGN(I)). The digital loop differs from the Mobile in several ways. The initial phase of each data burst is determined by combining the P1 and P2 preambles and loading the resulting phase estimate into the phase register of the loop. The loop phase is then used as a reference to rotate the incoming symbols. The rotated I is used for the soft decision and the rotated Q*SGN(I) is used as the phase error term. The contents of the loop filter frequency register is used to update the frequency synthesizer at the end of a data burst. When data is not present, the phase loop is inactive.

There is no loop for DPSK. Instead, the dot product of the current symbol and the previous symbol is taken. The result forms the 3-bit soft decision that is ultimately fed to the Viterbi Decoder.

Hub Timing Loop

The time tracking loop in the Hub is almost identical to that of the Mobile. The Hub timing loop bandwidth is 15 Hz. Figure 6-9 is a block diagram of the Hub timing loop. The timing loop is active only during preambles and when data is present (controlled by the Data Present line in the diagram). It is suspended when no data is present.

Hub AGC Loop

The Hub AGC loop is identical to the Mobile AGC loop.

Hub Fading Model

The Hub fading model data generation is identical to the Mobile fading model. However, the application of the fading data differs. In the Mobile both the signal and other user interference fade together. In the Hub only the signal fades (the noise/interference does not).

Hub Simulation Restrictions

All simulation runs were made at the 9.6 kbs data rate. The time loop was simulated at the symbol level. Chip level simulations would have been 100 to 1000 times more costly in CPU time. Acquisition of the Mobile by the Hub was not simulated. Acquisition is similar to that of the Mobile since, during acquisition, the Mobile will provide a continuous signal. A wide bandwidth phase lock loop will be used to get a frequency reference. When the frequency and timing information are known, the tracking loops described in this section will apply.

Hub Simulation Results

Figures 6-10 through 6-13 show the simulation results.. Figure 6-10 shows four BPSK bit error curves and one DPSK curve for comparison. The first curve is a Rc=12/35 punctured code with a perfect phase and time reference. It is followed by a modem implementation curve showing the effects of phase, time, gain and quantization. The third curve shows the effect of Ricean fading and no shadowing (Kf=10). The fourth curve shows fading (Kf=10) and shadowing with mean attenuation of 0 dB and a standard deviation of 3 dB. It should be noted that this BPSK curve flattens out and stays in the same general vicinity (although not shown, the 7.5 dB mean attenuation curve behaves similiarly). By comparing the DPSK curve to the BPSK curve, it can be seen that DPSK outperforms BPSK in shadowed environments. Figure 6-11 shows the equivalent DPSK curves. It also shows reasonable performance under heavy shadowing (mean attenuation of 7.5 dB). Figures 6-12 and 6-13 show the frame errors rates under the same conditions for both BPSK and DPSK.

EXHIBIT J.

TR45.5/92.06.____

CDMA FORMAL FIELD TEST REPORT

Test Results for November 18 - 23, 1991

Presented to:

Telecommunications Industry Association
Washington, D.C.
June 8-12, 1992

Frank Quick, 619-597-5507
Roberto Padovani, 619-597-5508

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QUALCOMM Incorporated
10555 Sorrento Valley Road
San Diego, CA 92121-1617

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Contents

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Figures

Tables

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1. Introduction

1.1 Contents

This test report consists of the following sections:

- Objective
- System Configuration
- Cell Site Information and Configuration
- Capacity Test Scenarios
- Capacity Test Results
    - FER Results
    - FER vs Speed Results
    - Cell Rx E_b/N_0 Results
    - Tx Power Results
    - Handoff Results
- Logged Data (in Appendix A)
- Drive Route Maps (in Appendix B)

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2. Objective

QUALCOMM's fully loaded capacity test of the CDMA system occurred in San Diego, California during the last two weeks of November 1991 to demonstrate digital cellular system capacity in a variety of operational environments. This test series was part of the high-priority functional tests defined by the CDMA Core Test Team, made up of licensed manufacturers and funded carriers.

The fully loaded system capacity tests yielded the call capacity of the system using actual and Markov-modeled voice phone conversations in the CDMA digital cellular network. These tests also demonstrated CDMA voice quality, system coverage, reverse link power control, forward link power control, call processing, handoffs (i.e., soft, softer, and three-way), and susceptibility to external interference.

The test included a variety of vehicle speeds, natural terrain's (i.e., canyons, hillsides, bays, and trees) and man-made structures (i.e., buildings, bridges, towers, freeways, and streets).

Testing from November 18- 23, 1991 entailed verification of the following scenarios that demonstrated the capacity of a fully loaded cell sector:

- **Single Sector Tests:** Mission Bay Gamma sector (Mission Bay Park). These tests were performed on November 18, 1991 and conducted on the Fiesta Island route.
- **Single Sector Tests:** Mission Bay Alpha sector (Old Town). These tests were performed on November 20, 1991.
- **Three Sector Tests:** Mission Bay Alpha sector fully loaded with other mobiles in Beta and Gamma sectors. These tests were performed on November 21, 1991.
- **Three Sector Tests:** Mission Bay Alpha, Beta and Gamma sectors equally loaded. These tests were performed on November 22, 1991.
- **Multi-Cell Tests:** Mission Bay Alpha sector fully loaded with other mobiles in adjacent cells and sectors including Mt. Ada cell, Mission Valley cell, Downtown cell, Mission Bay Beta sector, Mission Bay Gamma sector. These tests were performed on November 23, 1991.

These capacity scenarios were used to demonstrate specific CDMA system functions and performance including handoff, power control, voice quality, external interference effects, and call processing. Five cells (three omni cells and two sectored cells) with up to 70 mobiles were used in the detailed scenarios. Call processing capacity included up to 12 voice calls and up to 61 Markov calls.

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3. System Configuration

The following tables briefly summarize system configuration for the capacity tests. Table 3-1 describes the CDMA system configuration for the San Diego area which includes cell sites, mobiles, vans, automobiles, communication equipment, and switching office.

Table 3-1. CDMA System Configuration

Cell Site Name	Location	Antenna Configuration
Downtown (DT)	Downtown San Diego	Omnidirectional
Mission Bay (MB)	South Mission Bay	Three sectored (a, b, g)
Mission Valley (MV)	Central Mission Valley	Omnidirectional
Mount Ada (MA)	North Central Clairemont	Omnidirectional
30th Place (30)	South East San Diego	Two sectored (b, g)

Mobiles		
70 Alpha-2 (all ASIC) mobiles	4 fully equipped vans with 4 mobiles each 21 cars with two mobiles each 5 cell sites with one static mobile each 7 spare mobiles	Vans were equipped with diagnostic monitors, ETAK, recording equipment, two-way radio, analog phone, and test equipment. Cars were equipped with two-way radios. Selected cars were additionally equipped with a diagnostic monitor.

QTSO	Capacity	Backhauls
PSTN voice lines Call capacity	12 lines Total of more than 60 calls	Microwave or T1 links to all cells via Black Mountain and the PacTel MTSO

Table 3-2 briefly describes the test scenarios and details the number of mobiles that were used in each run. The table contains the configuration of the Other User Noise Simulator (OUNS/OCNS) and describes the distribution of the mobiles in each of the testing days.

Table 3-2. Mobile Configuration

Day	Test Scenario	Runs	Mobile Distribution	OUNS/ OCNS	Mobile Locations
11/18	Fiesta Island Single Sector - Mission Bay (Gamma) Isolated sector Test	1,2,3,4: 5,6: 7,8: 9:	30 Mobiles 40 Mobiles 50 Mobiles 61 Mobiles	No No No No	Mobiles evenly distributed within Gamma sector coverage area on Fiesta Island loop route with the exception of cell mobiles.
11/20	Old Town Alpha Sector Only Isolated Sector Tests	F1,F2, F3,F4: F5,F6: F7,F8: C1: C2: C3,C4:	30 Mobiles 33 Mobiles 25 Mobiles 30 Mobiles 10 Mobiles 10 Mobiles	No No No No Yes Yes	Mobiles evenly distributed within Old Town routes and adjacent areas
11/21	Old Town Alpha Sector with Beta and Gamma	1,2,3: 4,5,6,7: 8,9: 10:	20 Mobiles 30 Mobiles 40 Mobiles 47 Mobiles	Yes Yes Yes Yes	Mobiles on routes in Old Town and adjacent area
11/22	Three Sector Test Mission Bay (Alpha, Beta, Gamma)	1,2: 3: 4,5: 6,7: 8,9:	60 Mobiles 58 Mobiles 60 Mobiles 63 Mobiles 66 Mobiles	No No No Yes No (New Outer Loop)	Mobiles on route in Mission Bay coverage area.
11/23	Old Town, Alpha Sector with other cells and sectors (MB Alpha, Beta, and Gamma sectors, Mt. Ada, MVC, Downtown Cells Active)	1,2,3: 4: 5,6: 7:	40 Mobiles 40 Mobiles w/interference 60 Mobiles 60 Mobiles w/interference	Yes Yes Yes Yes	Mobiles on routes in Old Town and adjacent areas, including soft handoff areas

Up to 70 Alpha-2 (all ASIC) mobiles were installed and used during the capacity testing in approximately 25 vehicles, including 20 rental cars, one boat, and four vans. The mobiles drove various routes.

Every mobile phone had an assigned MIN (Mobile Identification Number). In this report, the MIN is the last two digits of the mobile phone number. Each testing van had four mobiles with different MINS assigned to each mobile.

Table 3-3 shows the daily MIN assignments used in the vans and various drive routes used on November 18, 20, 21, 22, and 23. A detailed description of the routes is presented in Appendix C.

Table 3-3. MIN Assignments and Drive Routes

Day	Route Description	MIN #s Assigned to Vans	
11/18	Fiesta Island Isolated Sector Tests (MB a)	Qualcomm Pactel Clarion Motorola	47, 84, 77, 91 39, 55, 62, 93 37, 43, 59, 89 44, 61, 86, 94
11/20	Old Town Isolated Sector Tests (MB a)	Qualcomm Pactel Clarion Motorola	47, 70, 84, 96 39, 62, 87, 93 37, 43, 59, 89 44, 61, 86, 94
11/21	Old Town All Sector Tests (MB a, b, c)	Qualcomm Pactel Clarion Motorola	47, 70, 84, 96 39, 62, 87, 93 37, 43, 59, 89 44, 61, 86, 94
11/22	All Sector Tests (MB a, b, c) Routes #s 3, 17, 11, and 14.	Qualcomm Pactel Clarion Motorola	47, 70, 84, 96 39, 62, 87, 93 37, 43, 59, 89 30, 66, 86, 94
11/23	All Cell/Sector Tests (MB a, b, g; MA, MV, DT) Routes 9, 16', 10', and 8.	Qualcomm Pactel Clarion Motorola	24, 47, 70, 84 39, 62, 87, 93 37, 43, 59, 89 30, 66, 86, 94

Parameters of the Mobiles Tested

The following parameters were used in each of the Alpha II mobiles during the capacity tests:

- Mobile Noise Figure.: 8 dB
- Mobile Tx Power: 23 dBm Max, 13 dBm Typical Max

4. Cell Site Information and Configuration

Five cell sites, described in Table 4-1, were used during the system capacity tests. Each cell site was staffed with QUALCOMM engineers who supported operations and data logging. In addition, each cell site was equipped with an Alpha-2 mobile for cell checkout, an AMI diagnostic monitor for logging and troubleshooting, and a two-way radio for communications to the command center.

Table 4-1. CDMA Cell Sites

Description
Mount Ada Cell (MAC) - Omni-Directional
The Mount Ada cell site is an omni-directional cell site that primarily services the Clairemont, Linda Vista, and University City areas.
The Mount Ada cell is located at 6426 Mt. Ada Road.
Mission Bay Cell (MBC) - Three Sectored
The Mission Bay cell is a three sectored (Alpha 135, Beta 240, and Gamma 350) cell site with low antennas (45 feet) that services primarily the Mission Bay, Loma Portal, and Old Town areas of San Diego.
Mission Bay cell is located at 4010 Hicock Street.
Mission Valley Cell (MVC) - Omni Directional
The Mission Valley cell site is an omnidirectional cell site with its antennas on top of a 12-story building and surrounding mesas at a similar height. It serves the Mission Valley and Fashion Valley areas in addition to covering the I-8 and Hwy-163 corridors in central San Diego.
Mission Valley cell is located at 591 Camino De La Reina.
30th Place (30C) - Two Sectored
The 30th Place cell site is a two-sectored (Beta 240 and Gamma 16) cell site that services primarily Golden Hill, North Park, and portions of downtown San Diego. This cell did not support any calls during the capacity tests.
The 30th Place cell site is located at 700 30th Place.
Downtown/Cabrillo Square (DTC) - Omni-Directional
The Downtown/Cabrillo Square cell site is an omni-directional cell site that primarily services the downtown area. Its antennas are positioned on top of a 16-story building.
The Downtown/Cabrillo Square cell is located at 1399 Ninth Avenue.

Table 4-2 describes the configurations of the five cell sites that were used during the system capacity tests from November 18 through the 23.

Table 4-2. Cell Sites Configuration

Cell Site Name	Configuration	Antenna Configuration
Downtown (DT)	20 Traffic Channels 1 Pilot Channel 1 Paging Channel 1 Sync Channel	Omnidirectional
Mission Bay (MB)	62-68 Traffic Channels (see note 1) 1 Pilot Channel per sector 1 Paging Channel per sector 1 Sync Channel per sector	Three sectored (a,b,g)
Mission Valley (MV)	16 Traffic Channels 1 Pilot Channel 1 Paging Channel 1 Sync Channel	Omnidirectional
Mount Ada (MA)	12 Traffic Channels 1 Pilot Channel 1 Paging Channel 1 Sync Channel	Omnidirectional
30th Place (30) (see note 2)	10 Traffic Channels 1 Pilot Channel per sector 1 Paging Channel per sector 1 Sync Channel per sector	Two sectored (b,g)

Notes:
1. Because OCNS occupies many traffic channels, the total number of traffic channels varied. upon the specific test that was run.
2. The 30th Place cell site was not used during the capacity tests.

Cell Parameters

The following parameters were used in each of the cells during the capacity tests:

- Cell power: 25 Watts (14 dBW), Independent of User Count (Pilot, Sync, and Access Channels: 5 Watts)
- Cell ERP: 100 Watts (20 dBW)
- Cell Noise Figure.: 5 dB

5. OUNS/OCNS Configuration

The Other Users Noise Simulator (OUNS)/Orthogonal Channel Noise Simulator (OCNS) is used during the system capacity tests to simulate the effects of other users in the reverse and forward links. It contains the following parts, with each simulating different effects of the other users:

- **The Other Users Noise Simulator (OUNS)** injects Gaussian noise into the two reverse link antenna paths and simulates the effects of other users in the same cell/sector and the contribution of other users in other cells.
- **The Orthogonal Channel Noise Simulator (OCNS)** injects orthogonal noise (on other Walsh channels) on the forward link and simulates the effects of other users in the forward traffic channels.
- **The Other Users Noise Simulator (OUNS)** is also capable of injecting Gaussian noise into the forward link; however, this was not used during capacity tests.

The Other Users Noise Simulator (OUNS) was set up in each cell before the start of the run. A typical configuration of the OUNS/OCNS would include the following:

- Setting the number of users that are simulated by the OCNS in each sector/cell
- Setting the number of users that are simulated in the "own" cell and the number of users that are simulated in the "other" cells

A description of the capacity test scenarios includes configuration tables that summarize the OUNS/OCNS settings for each day of testing.

Open Loop Calibration

Test data from the field tests shows that the open loop operation of the OUNS was correct and calibrated, (i.e., given a number of simulated users and their assumed average operating E_b/N_0, the correct average noise level was injected at 70 MHz in the receivers). This means that the power that N users operating at a given E_b/N_0 generate, referenced at the AGC circuit shown in Figure 5-1, is equivalent on the average to the power that the OUNS injects referenced to the same point.